

# Latest Generation CMOS Hybrid Focal Planes: First Astrometric Results

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## ABSTRACT

We present the first ground-based astrometric testing results conducted using the second-generation H4RG-10 A2 CMOS hybrid detectors. USNO is currently developing very large format CMOS hybrid focal plane technologies for use in astrometry and photometry. The results presented here are the latest in a series of calibration and astronomical tests that have been conducted for this purpose. Specifically we present the preliminary results of our astrometric analysis.

**Introduction:** CMOS focal planes have a flexible readout structure that is ideal for astronomical applications, however the low fill factor and higher noise properties typical of these detectors have hitherto precluded their use for astrometric applications. On the other hand, CMOS hybrid focal planes have the readout flexibility of the traditional CMOS with significantly reduced noise and the fill factor of a standard CCD. For these reasons, the United States Naval Observatory (USNO) is currently developing very large format CMOS hybrid focal plane technologies for use primarily in astrometry.

USNO has been testing large format, Teledyne Imaging Sensors (TIS) H4RG Hybrid Visible Silicon Imager (HyViSI) Sensor Chip Assemblies (SCAs) since the development of the first generation-A1 detector in 2006 (Dorland et al. 2007). Indeed, USNO has continued to support a myriad of H4RG development efforts, including the maturation of a second generation-A2 H4RG with significantly lower dark current than the A1 predecessor. This paper summarizes the first calibration and astrometric results for one such science-grade H4RG-10 A2 SCA.

**H4RG Calibration Testing and Results:** Dark current, read noise and flat field measurements were taken in the Astrometric Calibration Laboratory (ACL), at USNO. The ACL has been equipped to support calibration of the USNO H4RG Ground Test Camera (GTC). The GTC was built by Goddard Space Flight Center's (GSFC) Detector Characterization Laboratory (DCL) to be high-speed, low-noise and to support all multiplexer readout options. Figure 1 shows the calibration set-up in the ACL at USNO. The baffle shown in the picture was designed by DCL and USNO to

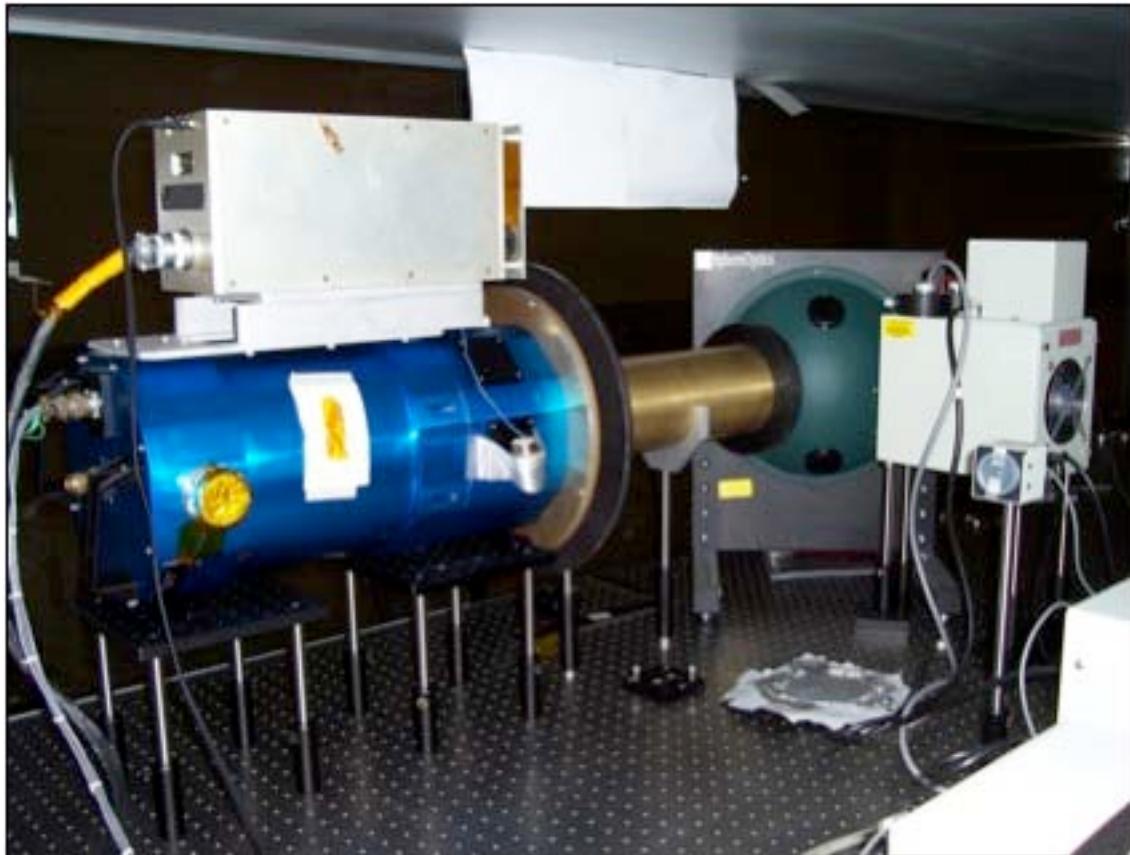
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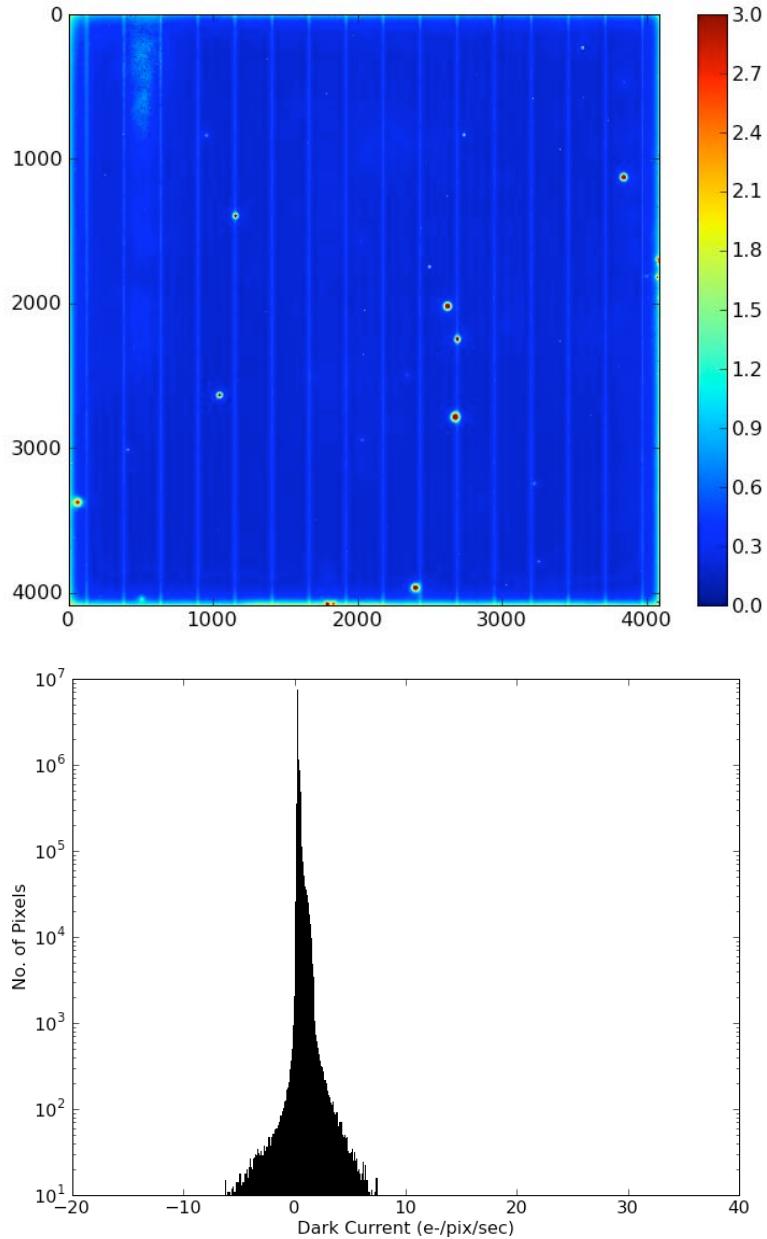
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ensure the GTC would receive light from the integrating sphere that is uniform to the 1% level. In the following we present initial dark current and read noise results. Linearity measurements are presented in Dorland et al. (2009).



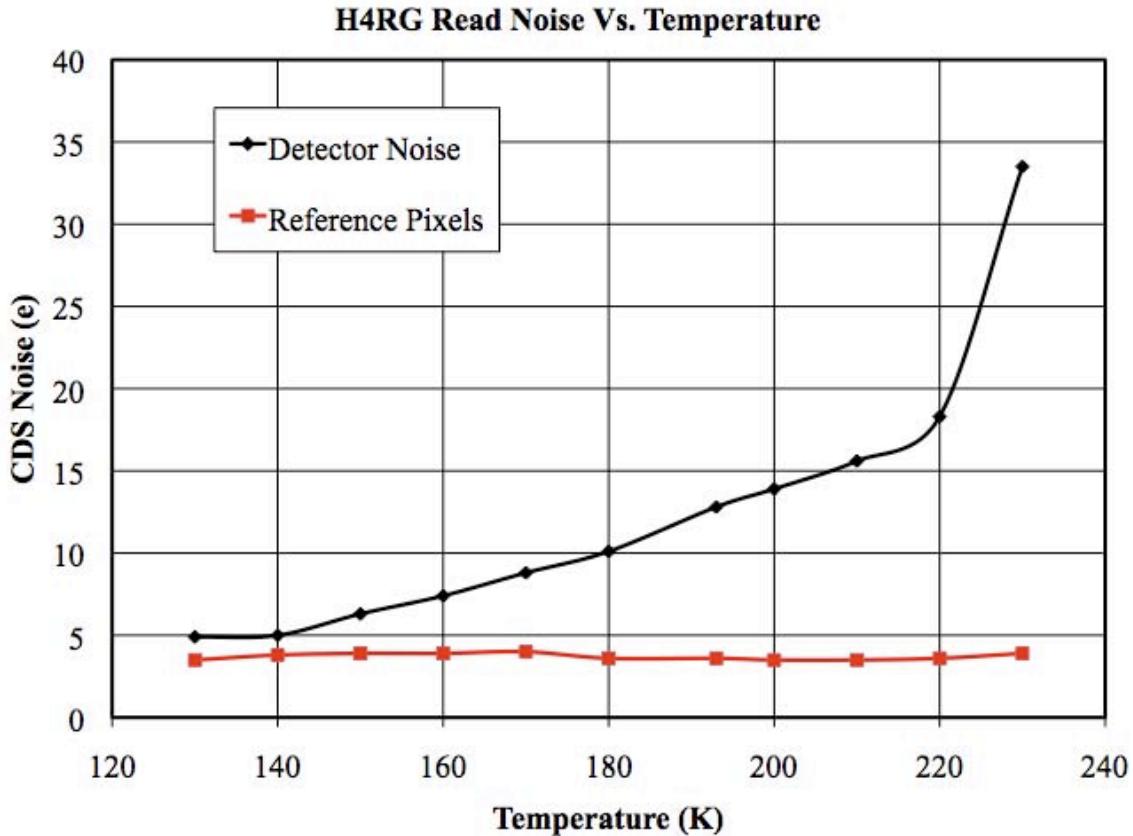
**Figure 1:** USNO Astrometric Calibration Laboratory Flat Field Set-up

Dark current measurements were taken as a function of temperature from 130-230K. At the nominal temperature of 190K, the mean dark current for the H4RG-10 A2 is well below 1 e/s/pix for the majority of the detector. The mean dark current at 190K of 0.3 e/pix/s for the A2 generation is more than two orders of magnitude improved from the A1 generation (30-40 e/s/pix, Dorland et al. 2007) and the population of hot pixels is significantly reduced. Figure 2 shows a histogram of the dark current at 190K and a clipped image of the dark distribution. As can be seen from the image, only a very small portion of the detector shows dark current in excess of 3 e/s/pix. The histogram is somewhat Gaussian with 18% of pixels showing dark current values more than 3-sigma above the mean.



**Figure 2:** Clipped dark current map at 190K (top). Histogram of dark current distribution at 190K (bottom). The mean dark current at 190K is 0.3 e/s/pix

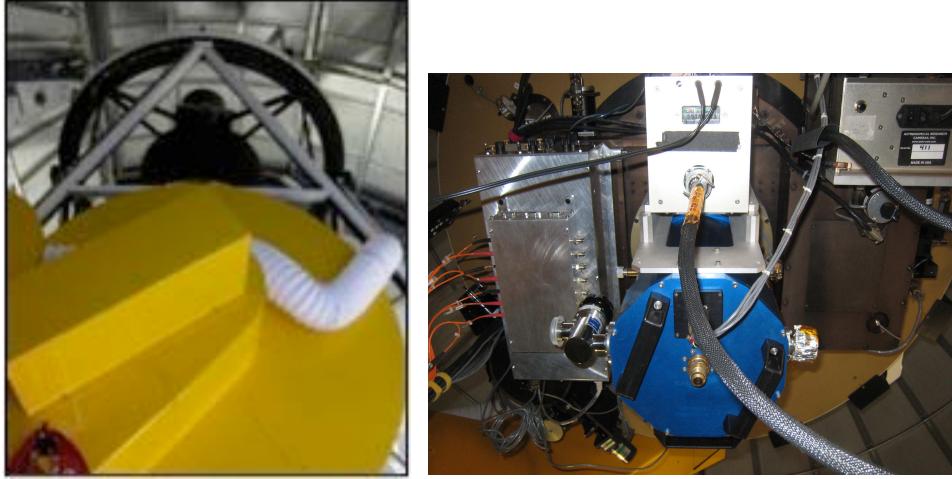
Read noise measurements were also taken as a function of temperature from 130-230K. Read noise values were calculated by fitting a Gaussian function to 45, 1-second, CDS-corrected frames and taking the average sigma over all 45 frames. In Figure 3 we plot the read noise as a function of temperature for the detector and the reference pixels. Above 140K the hybridized pixels show an increase in read noise with temperature, while the unconnected, multiplexer reference pixels do not. These results suggest that the multiplexer noise is independent of temperature and that the excess, temperature-dependant noise is instead being produced by the detector layer.



**Figure 3: Read noise as a function of temperature 130-230K for hybridized-detector pixels and unconnected-reference pixels.**

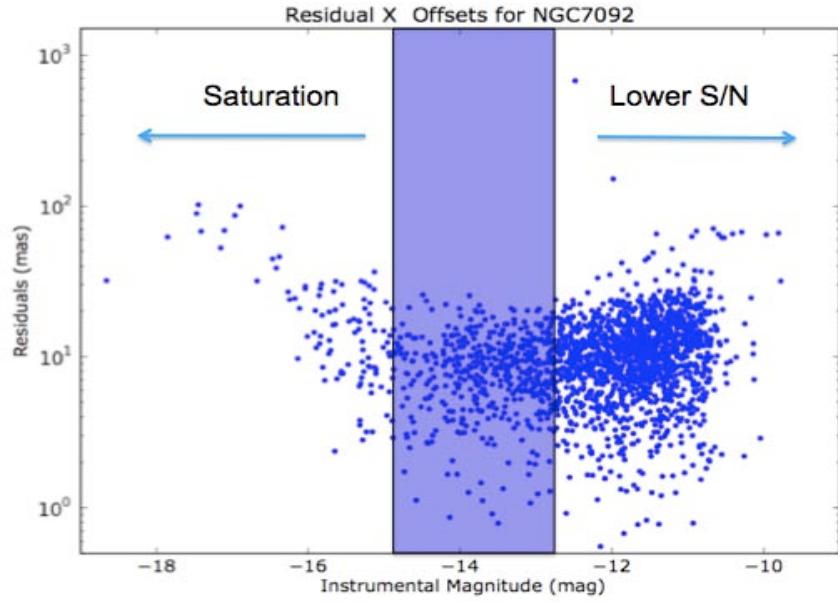
**Astrometric Testing and Result:** The H4RG GTC was deployed to the Naval Observatory Flagstaff Station (NOFS) in August 2009 for astrometric testing on the NOFS f/4.1, 1.3-meter telescope. Figure 4 shows the H4RG on the telescope. The detector was operated at  $\sim 190\text{K}$  and all images were taken using the Cousins I-band filter ( $\sim 700\text{-}900\text{ nm}$ ). The  $10\mu\text{m}$ , H4RG pixel corresponds to a 0.4 pixel subtense on the 1.3 meter. Multiple astrometric observations of NGC7092 (open cluster) and M13 (globular cluster) were taken over six nights. NGC7092 and M13 were chosen because they contain stars spanning a wide I-band dynamic range. The seeing was no better than 2 arcseconds over the course of all six nights.

To minimize distortion effects from the 1.3 meter optics, images of each field were taken within 1.5 hours of each other and the field center was translated no more than 10 pixels between images. For the analysis a reference image is chosen from 5, 205 second images. All other images of the field are mapped to this reference image. The translations, angles, and plate scale differences were calculated for each translated image using an Affine transformation. The position offsets from the reference image for each star are then recorded. The standard deviation of the offsets for each star across all images represents the final astrometric error for each star.



**Figure 4: NOFS 1.3 meter telescope (left) and the H4RG GTC on the 1.3 meter**

Initial astrometric results showed errors no lower than 25—30 mas. This is significantly higher than the  $\sim$ 8-10 mas range expected from uncorrected atmospheric and telescope effects. After exclusion of the lower 20% of the active detector area, the results shown in Figure 5 were obtained. An astrometric “sweet spot” is shown between instrumental magnitudes -15 and -13. The mean astrometric precision in this region is 8—9 mas, consistent with some combination of atmospheric noise (Zacharias 1996) and uncorrected telescope effects. This base noise sets an upper limit of approximately 1/50th of a pixel for the level of astrometric precision supported by the H4RG-10 A2 generation of detectors.



**Figure 5: Residuals for 5 images taken of NGC7092. These results indicate astrometric precision in the 8-9mas range, and are likely dominated by atmospheric noise and uncorrected telescope systematic errors.**

**Summary:** Our initial calibration testing of the H4RG-10 A2 generation of detectors indicates that the dark current has significantly improved over the A1 generation. Our astrometric results indicate that 80% of the detector performs as well as dedicated ground-based astrometric CCDs. However ground-based testing has also revealed a problematic region of the detector, which constitutes nearly 20% of the active area. Further ground based testing and calibration testing is needed to fully understand this problematic region and its effect on the astrometric capabilities of the detector.

### **References:**

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